SOIL STRATIGRAPHY IN THE MURRAY VALLEY AT ALBURY-WODONGA: A NEW APPROACH TO SURFICIAL STRATIGRAPHY

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Abstract: The valleys of the Murray River and its tributaries at their debouchments from the mountain ranges consist of multistep landscapes which include alluvial terraces, flights of alluvial or colluvial fans, and residual ridges or spurs and hills with several concordant upper levels.

A soil-stratigraphic study of types of soil-profile development and geomorphic relationships led to the recognition of fourteen soil-geomorphic units which have been named 'pedo-morpholiths'

For the separation of the soils of different ages, a special study of deep-seated pedogenetic features below the sola was needed because of difficulties in using the sola alone.

The study was originally confined to the valley lowlands but was extended and correlated with denudational landforms of the higher valley sides, where a sequence of valley pediments and basin-shaped, dell-like valleys were found to be related to the older units of the alluvial sequence.

Three main periods of geomorphic development have been recognised. The characteristics of the oldest development are broad, 3-7 km wide, trough-shaped valleys, and smooth, well-rounded topographic highs which grade with long gentle footslopes to the valley floors. Deep weathering zones, 70-130 m thick, commonly with heavy clay layers, are found in these localities, and lateritic weathering patterns are often exposed along the margins of these valley remnants. Two pedo-morpholiths have been related to this period.

The second period of landscape development involved four pedo-morpholiths. Major valley steps were shaped by valley dissection in which there were two different major processes: firstly narrow, deep, stream incision, and secondly broad landscape degradation leading to pediment-like forms and basin-shaped valleys or dells. Extensive hillslope colluvia, pedisediments, and thick valley fills were deposited. The two older pedo-morpholiths of this period are characterised by clayey red earths and krasnozems and in places show lateritic weathering patterns. The next younger pedo-morpholith is dominated by deep, dark grey-brown clays, and the youngest pedo-morpholith shows a unique two-storey B-horizon which provides a reliable soil-stratigraphic marker.

The development of the third geomorphic period involved eight pedo-morpholiths which mainly affected the central low belts of the valleys and resulted in terraced alluvia and smaller stepped colluvial fans.

INTRODUCTION

A tentative interpretation of the soil stratigraphy in a number of tributary catchments of the upper Murray Valley in Victoria (Rowe 1967, and unpublished data) revealed a number of problems in both interpretation and correlation of layered soils. Studies of features resulting from deep-seated pedogenesis in palaeosols on the adjacent Tablelands to the northeast in New South Wales (van Dijk 1969, and unpublished data) were found to be useful in clarifying such problems.

A joint study of soil-stratigraphic relationships was initiated in the Wodonga district of Victoria, at the debouchment of the upper Murray stream system onto the Riverine Plain (Figs. 1 & 2) with the objective of elucidating the basic soil-stratigraphic sequence, so that prediction might be made about the soil pattern through the region.

The landscape of the study area is characterized by a pattern of broad valley plains (Fig. 3) between stepped ridges and low hills; typical cross-sections are illustrated in Fig. 4. Extensive, thick mantles of transported material which was deposited in these valleys show an abundance of distinct sequences of soil layers. There are extensive, well-separated alluvial terraces along the streams, and the higher flanks of the valleys

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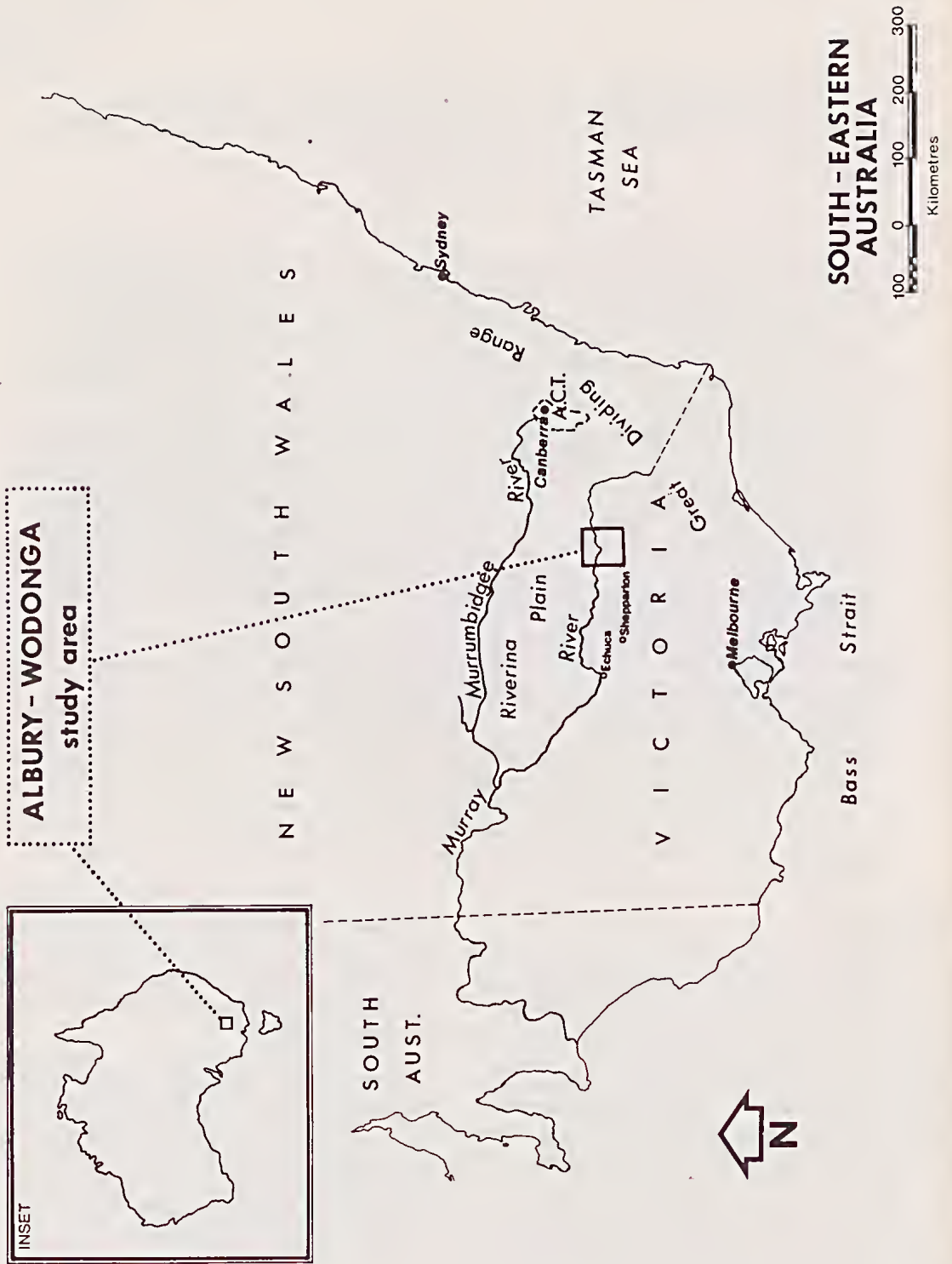†Soil Conservation Authority, 378 Cotham Road, Kew, Victoria, 3101.
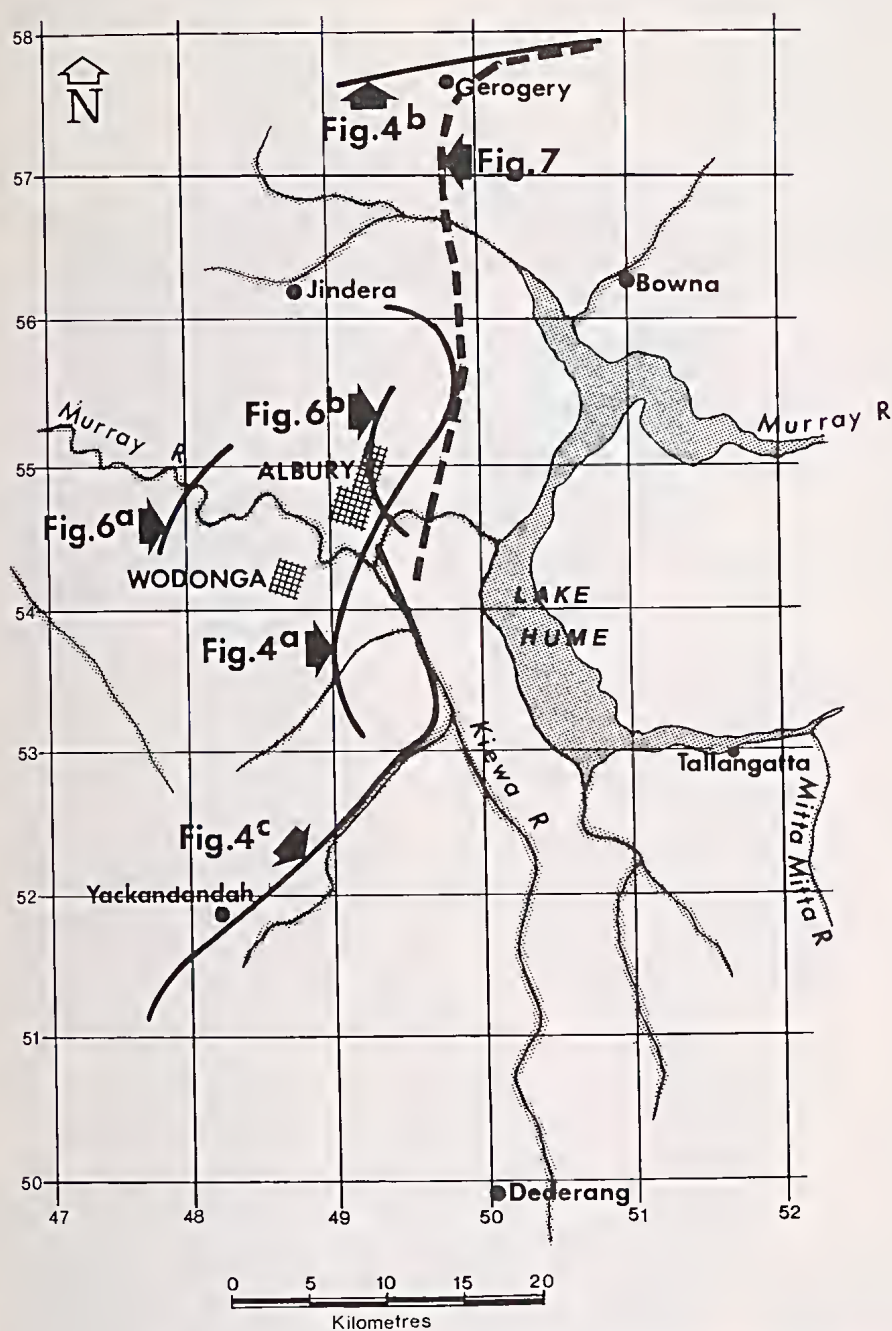
Fig. 1—Location of the study area.

Fig. 2—Location of the sections of Figs. 4, 6 and 7. (The reference grid is taken from the topographic maps 1:250,000.)

Mu : Murray valley plain
Mi : Mitta Mitta valley plain
Ki : Kiewa valley plain
Ge : Gerogery valley plain
Ji : Jindera valley plain
Th : Thargoona valley plain
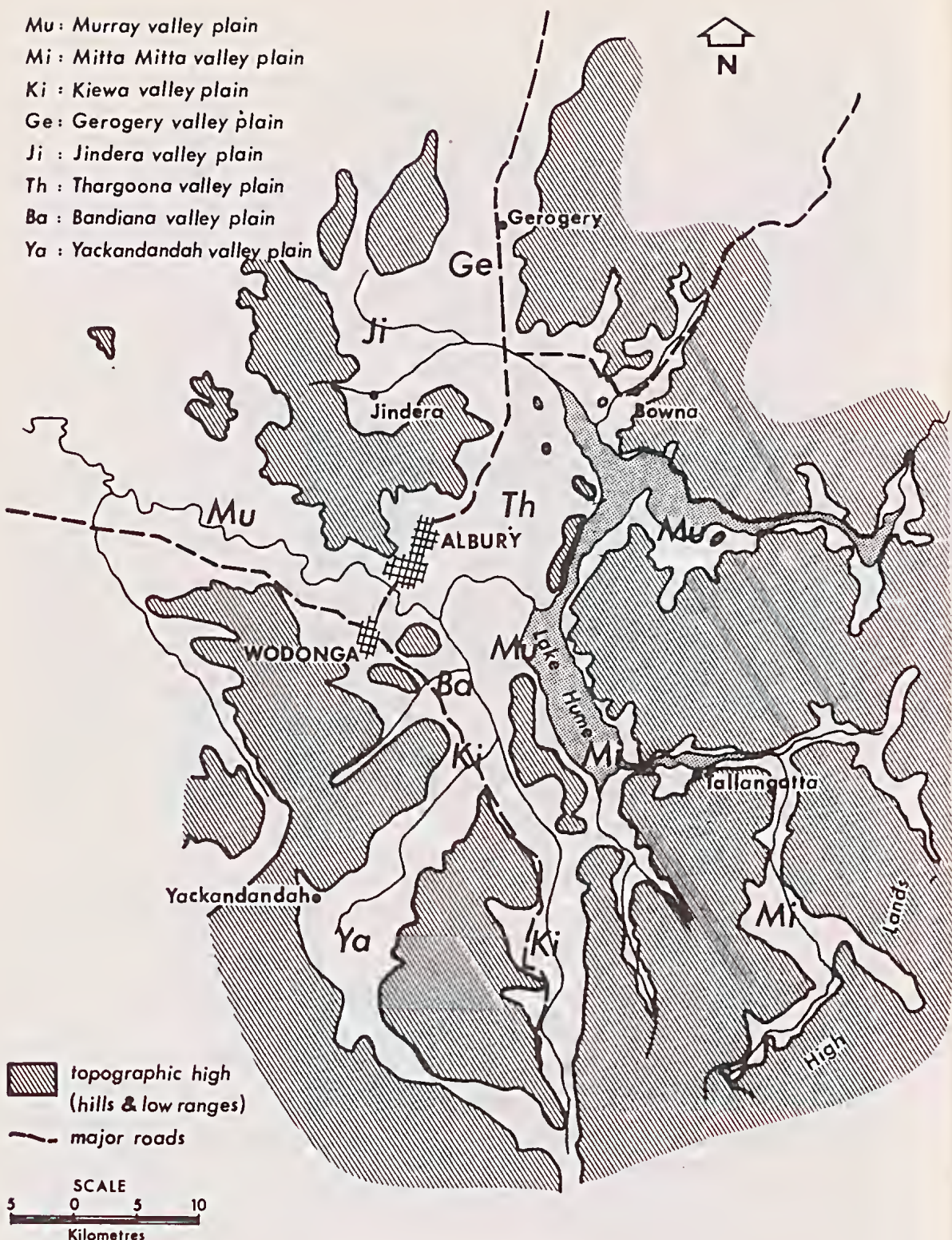Ba : Bandiana valley plain
Ya : Yackandandah valley plain

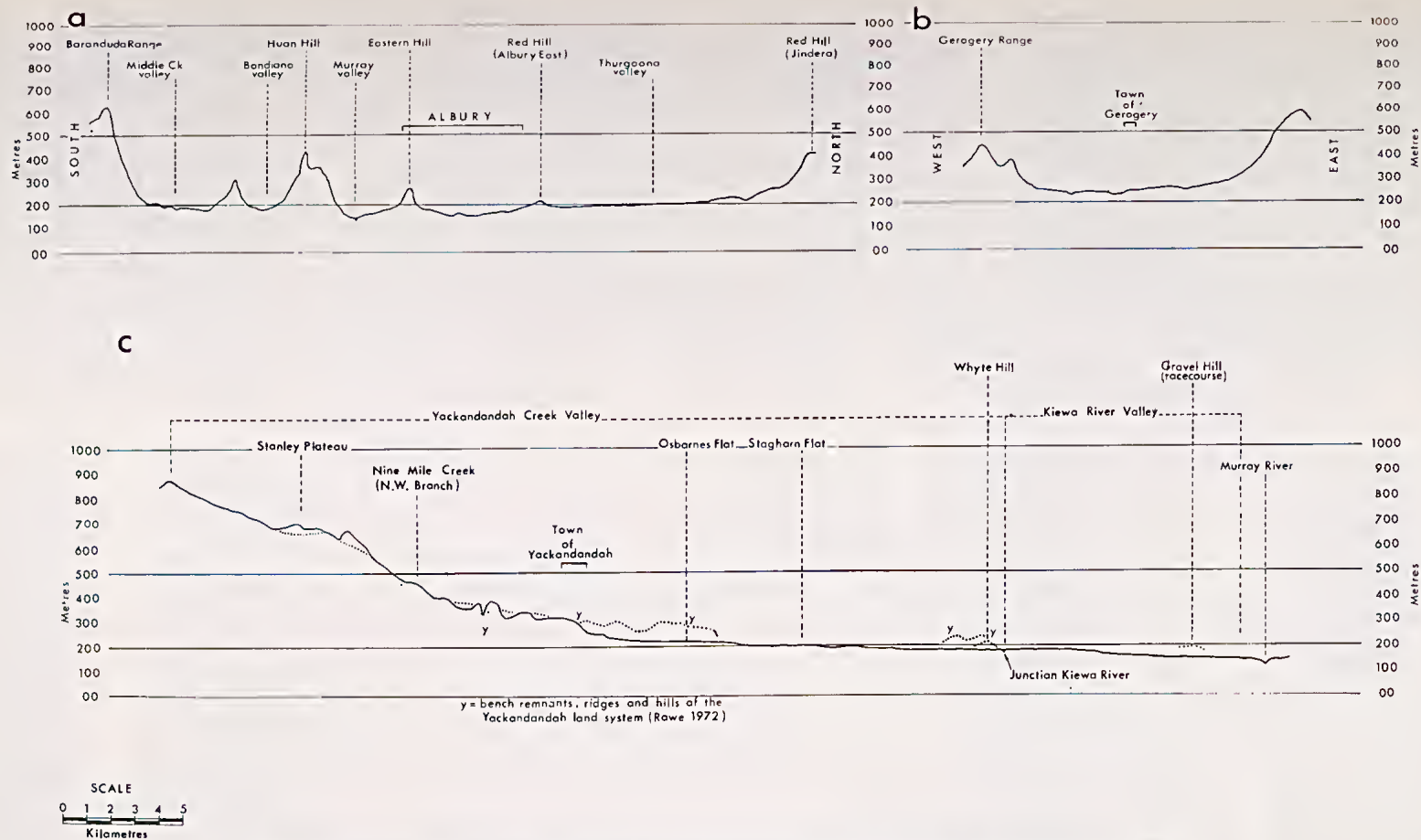Fig. 3—Pattern of valley plains and topographic highs in the Albury-Wodonga region.

Fig. 4—Sections illustrating the general valley physiography in the Albury-Wodonga region. (The locations of the sections are shown in Fig. 2.)

are lined with multi-layered colluvial deposits and impressive fan-in-fan formations.

The region is also valuable because it presents a direct link for soil-stratigraphic correlations along continuous major valley formations between the highland valleys and the Riverine Plain where much is known about soil-age relationships (see Butler 1959, 1967, Lawrence 1966, van Dijk 1978).

BASIC PRINCIPLES IN THIS STUDY

The following principles underlie our approach in this soil-stratigraphic study:

1. THE PEDO-MORPHOLITH CONCEPT

(i) *Definition:* The basic soil-stratigraphic unit used in this study is the 'pedo-morpholith'.[1] The term was originally introduced as a basic provisional unit in the description and correlation of sequences of colluvial and alluvial soil layers where surface form of the depositional body is an important correlation criterion (van Dijk *et al.* 1968).

A pedo-morpholith is composed of alluvial or colluvial material or, as commonly occurs, combinations of both. It is identified by (1) *specific surface soil and deeper-seated weathering patterns;* (2) *the nature of the sediment;* and (3) a *characteristic limited range of landscape forms* with the relative scale and proportion related to the local environment. (See also later p. 115 *et seq.*)

Ruhe (1956) introduced the term 'geomorphic surface' as a formal unit in soil-stratigraphic studies in which particular attention is paid to surface form. The use of that term in the present study does not seem appropriate because of its restricted meaning.

(ii) *The Problem of Periodicity:* A set of fourteen different pedo-morpholiths was recognised in the present study. This set has been interpreted as being related to an age-sequence by virtue of the stratigraphic relationships and contrasts in weathering of the units.

At this stage no formal claims are made with respect to the causes of the apparent periodicity in development and for this reason, the term 'groundsurface', the unit hitherto employed in soil-stratigraphic studies in adjacent regions (Butler 1967) has not been adopted, although the present study is in fact an extension of the groundsurface approach. The groundsurface is strictly a time rock-unit, and besides this, refers specifically to developments related to climatic

periodicity. The development of a time-stratigraphic sequence will depend on further field investigations of wider geographical extent.

The introduction of the pedo-morpholith as a provisional regional soil-stratigraphic unit permits the development of systematic studies of periodic phenomena in soil mantles through a series of successive approximations, with the pedo-morpholith sequence providing an informal framework for displaying regional soil-layer relationships as knowledge accumulates. This facilitates early publication of available soil-stratigraphic information without the need to meet the strict requirements of formal stratigraphic procedure. The definition of formal soil-stratigraphic units may then proceed, using the proposed term pedoderm (Brewer *et al.* 1970) when further detailed local studies have validated the general pedo-morpholith framework.

2. CRITERIA USED FOR IDENTIFICATION AND CORRELATION OF PEDO-MORPHOLITHS

The main criteria for the identification of the pedo-morpholiths are (i) pedological, (ii) sedimentary, and (iii) morphology characteristics. These may be given different emphasis during field studies; for instance, pedogenetic features play the major role in interpreting soil exposures, sedimentary features in establishing local continuities, and morphology in rapid broad-scale correlations such as the study of relationships to drainage basin topography.

(i) *Pedological Criteria:* A particular characteristic of this study was the intensive use made of deep-seated pedogenetic features. Using the characteristics of the upper A-B horizonation of the soil profile only, i.e. the solum,[2] to a depth of 1.5 m which is the traditional basis for classifying soils, presented great difficulties for stratigraphic correlation.

The deep-seated features occur extensively in the district and are particularly well developed in moderately low topographic sites. Most seem to be related to restricted drainage conditions and seepages (van

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[1]The term pedo-morpholith is derived from two terms from the literature of stratigraphy: (1) the term morpho-stratigraphic unit, introduced by Frye and William (1962), and (2) the term pedolith proposed by Crook and Coventry (1967).

[2] The term 'solum' has been used in a limited sense. According to common practice the solum includes both A and B horizons to the total depth of observable pedogenetic alteration of the parent material, but in the present study a maximum depth limit of about 150 cm has been adopted. The soil profile features down to this depth are chiefly determined by environmental surface influences and biological activity, and below this depth the features are more related to specific deep-seated weathering and subsurface water regime. This depth limit is generally indicated by a more or less abrupt change in overall character of the soil and may be marked by a more or less bleached zone as shown in profiles AW4 and 8 of Fig. 5 which testifies the pedogenetic significance of the boundary.

Dijk 1969). They therefore have minimal development in the better-drained upslope situations, and grade to non-specific general types of hydromorphic different-iations at the lowest and wettest sites. Each pedo-morpholith has its own specific range of deep-seated features which facilitate recognition and correlation (see Fig. 5).

This method of soil-layer correlation, using the criteria of the deeper profile features, is in contrast to the practice followed elsewhere in which only the upper soil profile of the weathering mantle is employed. Morrison (1965) regards the deeper zones of weathering as being less diagnostic than the upper part of the soil profile. This difference in viewpoint is probably due to the different environments of the areas examined. The deep-seated features of soils in the present study area seem, for the most part, to result from particular soil drainage conditions, which have been controlled by the specific topographic, climatic and overall soil-mantle conditions. These almost cer-tainly differ markedly from those in North America examined by Morrison.

(ii) *Sedimentary Criteria:* Sedimentary stratifi-cation can provide valuable evidence for establishing local continuities within pedo-morpholiths and particu-larly in verifying merging contacts. However, sedimentary criteria are generally less useful in iden-tifying and correlating the pedo-morpholiths. This is because of the general lack of consistent differences between successive pedo-morpholiths, great com-plexities in the local stratification and, in older pedo-morpholiths, the masking of detailed characteristics by intensive clay-forming. For instance, the dense heavy clays of the Baranduda pedo-morpholith (AW9, Fig. 5) are not as uniform in texture as their frequently featureless appearance suggests.

(iii) *Morphology Criteria:* Morphology as a main criterion in the correlation of erosional-depositional developments is used for both detailed and broad-scale developments.

Depositional land forms may contain easily recognizable features such as terraces and fans varying in shape, size, and gradient, but there are also less obvious form contrasts which may be significant. Here we would cite differences in scale. For example a remnant of the alluvium of one pedo-morpholith may consistently be present as a narrow bench, barely sepa-rated vertically from the valley floor, whereas in another it may have the form of a broad terrace elevated many tens of metres above the present flood-plain. Similarly, when considering alluvial-colluvial fans, small fans covering only a few square metres may be typical of a particular pedo-morpholith but another may, under similar climatic conditions, form extensive deposits many hectares in extent. Moreover, colluvial

hillslope deposits may form only thin veneers, in which case they are difficult to identify as a component of a pedo-morpholith distinct from the underlying material, or they may be several metres thick and show independent morphology.

Although the larger pedo-morpholiths may often be shown to be older, local variations in form and position in the landscape need not follow this trend and small remnants of older units may be found as inclus-ions within younger units of larger dimensions.

Erosional land forms have been found to con-tain important criteria, particularly for recognizing landscape sculpture associated with the older pedo-morpholiths. These land forms consist of pediment-like surfaces and basin-shaped valley plains of varying size and shape which are apparently the result of vigor-ous surface wash processes. For the smaller basin-shaped valley plains the term 'dell'[3] is proposed while the larger forms are similar to the 'Pediplain Basins' of van Dijk (1959) and van Dijk and Woodyer (1961).

The discussions of land form criteria in the present paper have been limited to general aspects and a more detailed, specific account will be presented separately.

THE PEDO-MORPHOLITHS
1. INTRODUCTION

The pedo-morpholiths are described in the order of increasing age. Principal pedogenetic dif-ferentiations between them are illustrated in Fig. 5. The soil profile characteristics shown in this figure represent developments which have occurred at low slope sites in the moderately well-drained class[4] and in moderately acidic parent materials. These are the con-ditions which apply to the most frequently observed field exposures in this area. The parent materials con-sist of the weathering products, either sedentary or mixed transported materials, from Palaeozoic sedi-ments and granites, and from Tertiary sediments (Bu-tler *et al.* 1973).

The soil profiles show marked differences in hydromorphic features despite the fact that they occur in approximately similar present soil drainage situa-tions. This is seen mainly as a reflection of the mar-kedly different climatic conditions under which the soils of different pedo-morpholiths developed in the past, and it is proposed to introduce the term 'hydro-

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[3] A dell is a small dry valley with a shallow, dish-like cross-section; the term was originally used for dry valleys associated with a specific periglacial climate condition (Fair-bridge 1968). The term has also been used for small dry valleys in general, irrespective of origin (Sharpe 1941).
[4] According to the soil drainage classification in Soil Survey Staff (1951).

TABLE 1

THE SEQUENCE OF PEDO-MORPHOLITHS IN THE ALBURY-WODONGA REGION

Geomorphogenetic grouping	Pedo-morpholith Symbol and numbers AW-	Name	Observed Main Occurrences of Pedo-morpholiths	
			(1) In the low relief of the central part of the valleys	(2) On the slopes of land of moderate relief on the sides and upstream portions of the valleys
I	I-a	0 Dorchap 1 Yabba 2 Ferndale 3 Noorongong	Minor terraced sheets and cut-and-fill insets on the lower plains of the major stream valleys	Thin sheets on lower parts of steep slopes; deeper sheets locally on dell-shaped lower slopes
	I-b	4 Boorgunyah 5 Barnawartha 6 Kergunyah 7 Mullagong	Low, usually narrow terrace-benches bordering the floodplains of the major stream valleys; layered, somewhat terraced fills of smaller tributary valley incisions; stepped fans at the outlet of side valleys	
II	II-a	8 Mudgeegonga 9 Baranduda	High terrace benches along the major stream valleys; broad low-angle fans, and sloping plains at the flaring outlet of side valleys	Extensive blankets on low- and mid-slopes Deep-seated substratum on lower dell-shaped slopes at the foot of higher hills
	II-b	10 Gundowring 11 Yackandandah	Isolated residuals of valley alluvium as spurs, low hills, small bench-remnants, and fills of small coves on the sides of valleys	Substratum on lower slopes of low hills and ridges of the higher margins and upstream sections of the valleys Sedentary and colluvial soils on higher margins and upstream sections of the valleys
III		12 Tallangatta		Sedentary and some colluvial soils on high margins of broad valleys
		13 Stanley	Very deep weathering, particularly at the heads of valleys and on major broad cols	

morphic reach' to describe these differences. Hydromorphic reach is intended to give an indication of the proportion of a normal slope section occupied by soils with hydromorphic features such as grey colours, high plasticity of the clay and sesquioxidic segregation throughout the soil mass. Four classes have been used as indicated in the diagram in the upper right corner of Fig. 5. In class 0 hydromorphic development is restricted to the near-level foot of a slope; in class 1 it extends from the foot onto the lower slope section; in class 2 onto the middle slope section, and in class 3 well onto the upper slope.

2. DESCRIPTIONS

The following descriptions present only the readily observable gross pedogenetic characteristics. They should be read in conjunction with Table 1. More detailed soil characterization will be given in a separate publication.

(i) The pedo-morpholiths of Group I occur mainly on the lower floors of the valleys of the major streams and tributaries.

Sub-group I-a. The four units of this sub-group Dorchap (AW0) (506524),[5] (AW1) (498502), Ferndale (AW2) (497544), and Noorongong (AW3) (495539), are the dominant components of the soil mantle of the lower plains of the major stream valleys which were mapped as the Coonambidgal Formation by Brumley *et al.* (1974). Their pattern is generally very complex, but clearly separated and well exposed units were observed near the junction of the Kiewa and Murray Rivers and in the lower Mitta Mitta Valley. There are related small localised bodies of colluvium in fills of ravines and as shallow sheets on dell-shaped lower slopes at the base of steep slopes. The soil-profiles show a minimal to medial degree of solum differentiation. A soil profile on the Ferndale pedomorpholith near the junction of the Kiewa and Murray Rivers at 497544 is a typical example with moderate solum development. Only the soil profile on the Noorongong pedo-morpholith, the oldest of these four units, has a narrow (30-50 cm) zone of weakly developed pedogenetic differentiation below the solum showing a fine pattern of clayskins in fine cracks and pores.

Sub-group I-b. The pedo-morpholiths of this subgroup, grouped because of geomorphic affinities, are well represented in the belt of alluvial terraces bordering the floodplains and usually 2-4 m above the latter. Only the youngest of these, the Boorgunyah pedomorpholith (AW4), occurs also extensively on the lower floodplains as observed particularly along the

[5]Grid references from 1:250,000 map sheets Wangaratta SJ55-2 and Tallangatta SJ55-3 for typical exposures.

Murray River west of Albury and Wodonga. A cross-section of the Murray Valley through the township of Old Barnawartha at 479545 (Fig. 6a) is used to illustrate the terrace relationships.

The Boorgunyah (AW4) is characterized by a soil profile showing a pronounced contrast between the solum and the deeper pedogenetic zone and represents a typical example of 'subsolum development' (van Dijk 1969). The sudden transition between the two zones, usually at a depth of 1.2-1.4 m may be marked by some bleaching. These deep-seated patterns are caused by variable development of sesquioxidic concretions and stains, clay cutans and pedotubules and are relatively coarse (0.5-2 cm in cross-section) but the soil mass as a whole is little changed by soil weathering.

A profile of the Boorgunyah is exposed in a high bank of a slightly domed floodplain ridge along the Murray River at 478549 (Fig. 6a).

In the soils of the three older pedo-morpholith units of subgroup I-b there is little contrast between the solum and the underlying soil horizons which gradually merge. There is however a progressive increase in depth of the profiles with age (Fig. 5).

A typical soil profile of the Barnawartha unit (AW5) is exposed along a section in a high road cutting in the first terrace level above the floodplain of the Murray River at 479547 (Fig. 6a).

The Kergunyah unit (AW6) is exposed in the banks of Splitters Creek at 483549 and along an adjacent eastern tributary, together with the Barnawartha unit at a slightly lower level on low angle alluvial-colluvial fans graded to terrace benches just above the floodplain of the Murray at 485548.

The Mullagong pedo-morpholith (AW7) seems of very restricted occurrence and only small terrace-bench remnants have been observed on the west side of the Kiewa Valley near Tawanga township, and in the Yackandandah Valley. A cross-section at the latter site about halfway between Allans Flat and Staghorn Flat (489521), shows a stepped terrace sequence of the alluvia of the Barnawartha, Kergunyah and the Mullagong pedo-morpholiths as a composite cut-and-fill in an extensive deposit of alluvium of the next older pedo-morpholith, the Mudgeegonga (AW8).

(ii) The pedo-morpholiths of Group II are the principal units of the undulating-rolling to low hilly topography of the valley plains.

Sub-group II-a. The Mudgeegonga (AW8) and the Baranduda (AW9) units are grouped together for three reasons.

Firstly, they both stand out as major, often locally extensive terrace formations some 5-8 m above the floodplains (Fig. 6b). Secondly, they are found

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The pedo-morpholiths of the Albury–Wodonga region,
reference symbol and numbers;

AW-	0	1	2	3	4	5	6	7	8	9	10	11	12	13

hydromorphic reach 1):

hr·0	hr·2	hr·0	hr·1	hr·1	hr·2	hr·1	hr·2	hr·0	hr·3	hr·0	hr·0	hr·?	hr·?

solum (ltd.) 2)

deep-seated pedogenetic differentiation

DEPTH 00 cm
20
40
60
80
100 cms
120
140
160
180
200 cms
220
240
260
280

bl

bl.

bl

?

DEPTH ?

DEPTH ?

+GD–pattern
5)

YD–pattern
5)

TL–pattern
5)

deep, intensive mineral weathering

Legend 3)

hydromorphic reach

common hillslope (max slope 5–8°)

A – horizon

B_1 – horizon

B_2 – horizon, well developed pedolity.

B_2 – horizon, earthy, moderate pedolity

B_2 – horizon, earthy, opedol

B_{2-ss} – horizon = subsolum 4)

B_3 – horizon

B_{3-ss} – horizon = subsolum 4)

C – horizon

bl = bleached horizon

1) hydromorphic reach = see diagram above and explanation in the text.
2) solum (ltd) = solum in the limited sense, see explanation in the text.
3) A, B_1, B_2 and B_3 = usage according to the Soil Survey Manual, 1951, U.S.D.A. Handbook N° 18.
4) ss = subsolum, von Dijk, 1969, and explanation in the text.
5) GD–, YD–, and TL–pattern, see text.

Fig. 5—Schematic illustration of the main features of soil profile differentiations which characterize
the pedo-morpholiths in in the Albury-Wodonga region. (The profile descriptions generally apply
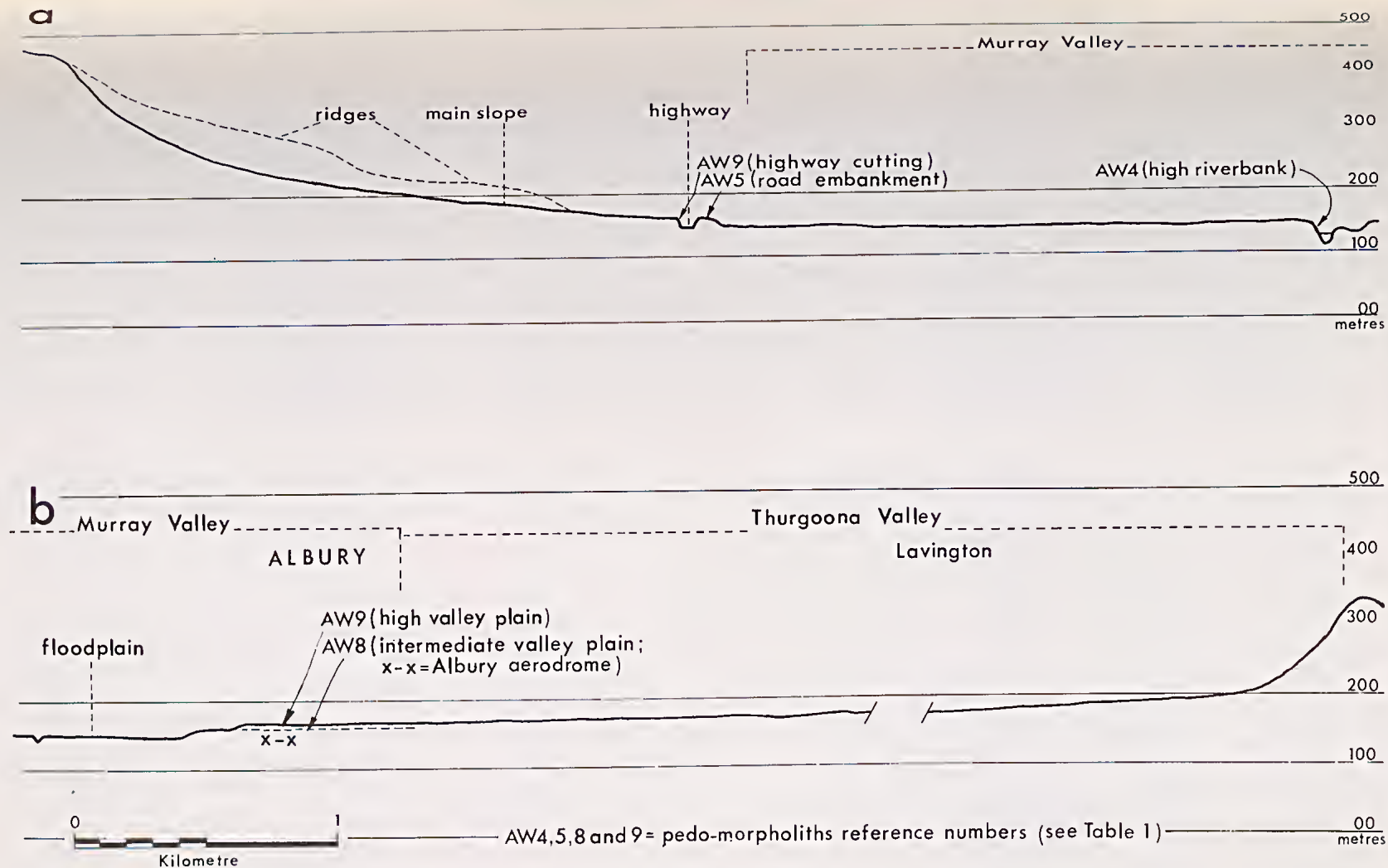to slope position x-x in the hillslope diagram.)

Fig. 6—Murray Valley sections. (Locations are shown in Fig. 2.)

together in the deep colluvial mantles of the lower section of long gentle slopes where they cause very conspicuous, strongly contrasting soil layering in roadside exposures. Thirdly, their erosional forms occur in a characteristic sequence in the head sections of small tributary valleys, showing a dell-in-dell arrangement.

The Mudgeegonga pedo-morpholith is widely distributed both on the higher valley floor margins and on hillslopes, whereas the Baranduda pedo-morpholith is present as thick mantles mainly on the floors of basin-shaped valleys and dells and on gentle footslopes at the base of higher relief, thinning out rapidly towards higher slopes.

The Mudgeegonga pedo-morpholith stands out, not only because of its wide distribution on both valley floors and hillslopes, but expecially because of its unique soil profile development.

The soils are characterized by a deep development comprising a duplex solum, usually with only moderate contrast between A and B horizons, and a deeper-seated zone (subsolum) with strong weathering similar to that of the B horizon of the overlying solum.

The A horizon is usually an apedal greyish brown to brown loam to clay loam, about 25 cm thick, grading over 5 cm to a well-structured reddish brown clay of the B horizon. The latter clay has well-developed multi-angular peds, of 2-3 cm size, breaking down readily to smaller aggregates, and the soil material is of friable consistence.

The B horizon grades to the clay subsolum at about 90-100 cm depth. There is a colour change to more yellow- and grey-brown. The subsolum clay also has well-developed pedality, with angular peds of 3-4 cm size. The soil material is somewhat more plastic than that of the solum.

Often the deeper zone differs markedly in colour and to a lesser extent in structure from the upper B horizon so that the profile as a whole appears conspicuously layered. In fact, it often strongly resembles profiles in which two soils of different age are superimposed, particularly when a bleached horizon with sesquioxidic segregations is present between the two soil layers.

The soils of the Baranduda pedo-morpholith contrast strongly with those of the Mudgeegonga because they are commonly dark grey clays, moderately dense and of high plasticity. The upper 2-3 m usually have well-developed pedality, with coarse prismatic peds (5-10 x 10-20 cm) with widely spaced slickensides. The degree of pedality diminishes rapidly in the lower part of the profile, though slickensides may still be present; the soil texture decreases to a somewhat lighter clay, there is less biotic homogenization, and less masking of coarser grain fractions by clay weather-

ing than occurs in the upper part of the profile, so that some of the depositional fabric remains visible.

In general, the predominant clay factor in the upper part of the soil profile of the Baranduda pedo-morpholith seems to be the result of intensive clay weathering and/or internal translocation rather than of depositional origin since it occurs not only in low-lying fills of gentle gradient but also in slope colluvia and fans with relatively steep gradients.

Because the Baranduda pedo-morpholith usually extends over a wide hydromorphic reach, it frequently occurs in sharp contrast with brown and red-brown soils of other pedo-morpholiths which occur alongside or overlie it, and in a few cases with red to red-brown soils of older pedo-morpholiths under it. These latter cases illustrate significant differences in hydromorphic reach. Another conspicuous feature of the Baranduda are thick, usually 0.5-1 m, but sometimes up to 1.5-2 m, grey hardpans in very irregular bands. These occur in stony colluvia at the base of steeper, high slopes or in colluvial fans of steep gradient at the outlets of small catchments.

Sub-group IIb comprises the Gundowring (AW10) and the Yackandandah (AW11) pedo-morpholiths which are the major units of the 'red' soil landscapes of the higher topographic positions on the valley plains, high bench remnants, high head sections of tributary valleys, and some isolated hills and ridges. A representative example of such soil landscapes has been mapped as the Yackandandah land system by Rowe (1972).

The Gundowring unit occurs extensively as colluvial mantles on the gentle slopes of this soil landscape, and in places there are large-scale fans and trails in the downstream portions of the valleys. Well-developed fans of this unit are found north-west of Dederang at 499501.

Residual hills, ridges, and narrow bench remnants consisting of red-coloured sandy or gravelly alluvium in the main valleys, to which the surface of the remnants of the Gundowring unit in the tributary valleys appears to be graded, indicate the original existence of high alluvial valley fills related to this pedo-morpholith. Examples of these occur in the Murray Valley near the junction with the Kiewa River up to the present 170 m contour line (e.g. at Bonegilla, 498543).

The soils of the Gundowring unit show intense weathering to considerable depths of up to 10 m and more. The common colour is strong red-brown and they are clay with earthy appearance in the lower profile, often with moderate to strong pedality (0.5-2 cm irregular peds). In many places there is a more or less strongly developed, grey to pale yellow coloured, vermiform pattern resembling filled in worm or root channels 1.5-2 cm in diameter.

Exposures of the Yackandandah pedo-morpholith are characterised by the presence of hardpans which have a conspicuous network of 2-4 cm wide pallid veins, 30-50 cm apart, in a red-brown to red groundmass (500538). They occur most frequently on higher valley floor levels at the heads of the tributary valleys but can be traced down the valleys on occasional bench remnants at a somewhat higher level than those of the Gundowring unit, for instance in the Murray Valley at the junction with the Kiewa River.

The characteristic morphological relationships of the Gundowring and the Yackandandah units are best seen at the heads of the larger tributary valleys such as the Yackandandah Valley. The Gundowring unit appears to be related to small valley basins of tributary streamlets and the Yackandandah unit to a broad, undulating higher level which represents the remnant of the floor of an old, wide, major valley head basin.

(iii) The pedo-morpholiths of Group III, the Tallangatta (AW12) and the Stanley (AW13), are represented by residuals on the very high margins of the valleys defining the outline of the valley plains. A limited examination only has so far been made, but two distinct developments can be traced throughout the region using both soil and geomorphic evidence.

The Tallangatta pedo-morpholith is identified by specific types of lateritic weathering patterns in the hardpans of remnants of ancient fans and high, sloping benches (515530). It occurs at high levels on the upper flanks of the valleys close to the steep valley sides. The dominant pedogenetic pattern is characterised by a very coarse irregular network of strongly cemented red-brown to purple-red material, 5-20 cm wide, enclosing somewhat softer pallid material 15-20 cm in diameter.

The Stanley pedo-morpholith is represented by a second high level of very strongly worn bench remnants, generally occurring in the main valleys some 20 to 30 m above the level of the Tallangatta landforms.

A characteristic change in slope physiography is associated with the high level of the Stanley pedo-morpholith. Above this level the general slopes have a relatively broad, even 's'-shape but below this level the slope physiography is more complex in detail, showing conspicuous breaks of slope and a stepped sequence of ridges, spurs, and hills.

The Stanley unit is particularly extensive along wider cove-shaped valley sections. Intensive and deep rock weathering has occurred at these high levels and is clearly evident in mining excavations at the head of the Yackandandah Valley (482516).

There is approximate correspondence between the levels of the remnants of the Stanley pedo-morpholith in the Murray Valley near Albury and those on the surfaces of the broad high-level valley corridors and associated broad valley basins in the Gerogery, Jindera, and Bowna districts north of Albury.

DISCUSSION AND CONCLUSIONS

Correlation of pedo-morpholiths and reconstruction of a soil-stratigraphic sequence are difficult because a complete sequence is seldom available at any local valley cross-section.

However, the reconstruction of a complete valley sequence from the data of several incomplete sequences is facilitated by the fact that the sequences mostly overlap. In addition, the independent use in correlation of two separate kinds of criteria, pedogenetic patterns and geomorphic characteristics contributes to reliability.

Correlations allow the reconstruction of a general soil-stratigraphic sequence for the Albury-Wodonga region which is presented schematically in Fig. 7 for a major valley section.

In the geomorphogenetic evolution of the landscape, as related to the pedo-morpholith sequence, three main geomorphogenetic periods may be recognised:

(i) During the first period, embracing the development of the pedo-morpholiths of group III (Table 1) a landscape formed apparently characterized by lowlands of wide, trough-shaped valley plains and higher land with very smooth, rounded hills with long gentle footslopes graded to the lowlands. The valley plains had a complex branching system in which individual branches either joined tributary valleys of adjacent catchments or rejoined their own system. An example of the former is the Gerogery Valley and of the latter, the Bandiana Valley (Fig. 3).

Another characteristic of the lowlands of this early landscape development is the deep zones (up to 90-130 m) of intensive rock weathering as revealed in the borehole information of the Water Resources Commission of N.S.W. Such thick zones of decomposed rock survived the degradations of the next episodes in many locations, e.g. on the Gerogery and Jindera valley plains (Fig. 3), and they are also common at the heads of tributary valleys on high bench remnants and 'hanging' floors of small tributary branches, for example west of Yackandandah township.

(ii) During the second main period, embracing the formation of the four pedo-morpholiths of group II (Table 1) the broken topographic relief of the valley plains was sculptured and three categories are recognised.
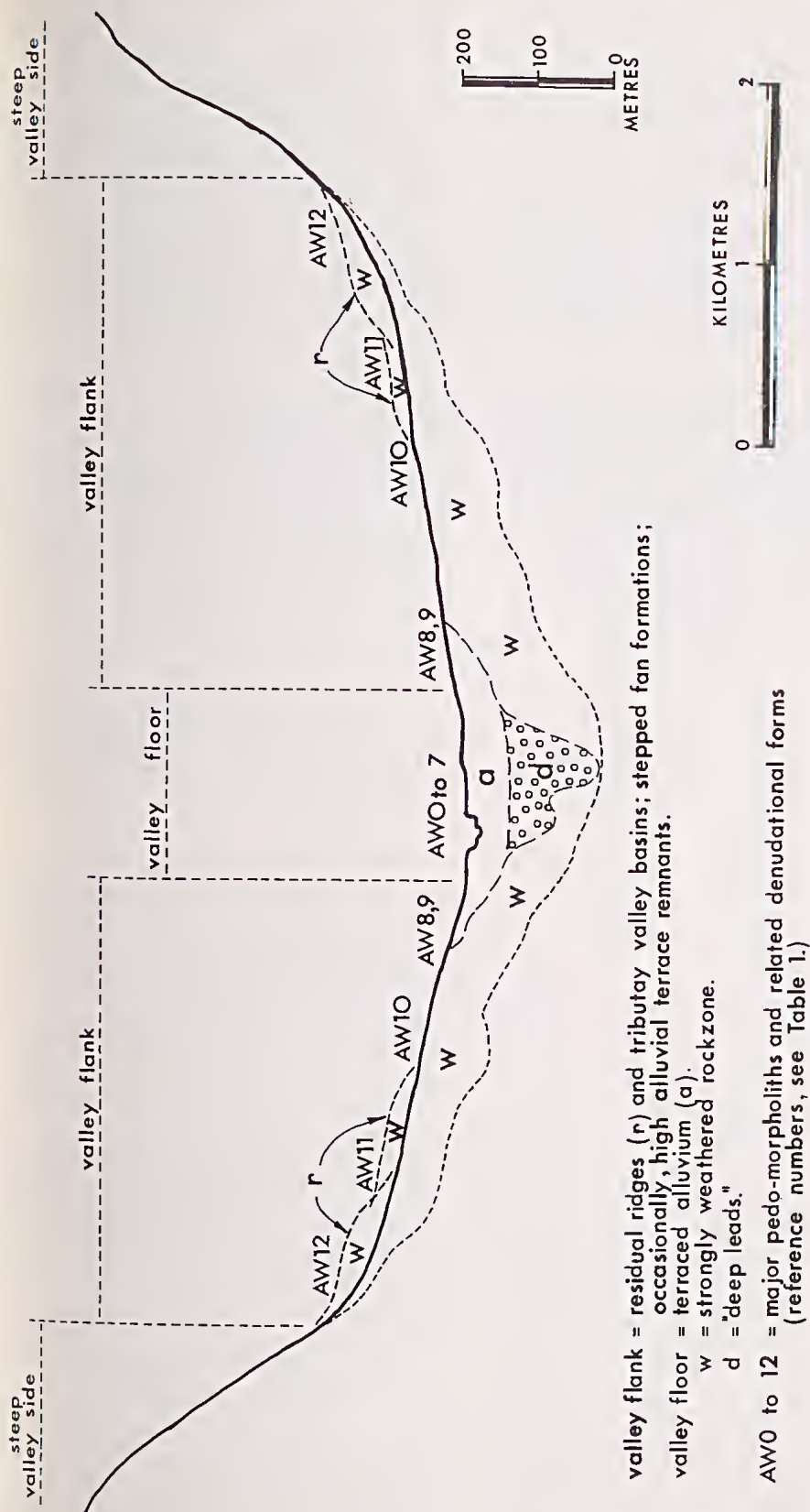
Fig. 7—Schematic soil-geomorphic section across the Murray, Thurgoona and Gerogery valley plains
(see Fig. 3). Location of section is indicated in Fig. 2.

valley flank = residual ridges (r) and tributay valley basins; stepped fan formations;
                occasionally, high alluvial terrace remnants.
valley floor = terraced alluvium (a).
        w = strongly weathered rockzone.
        d = "deep leads."

AW0 to 12 = major pedo-morpholiths and related denudational forms
            (reference numbers, see Table 1.)

Fig. 8—Schematic cross-section of a tributary valley in the Albury-Wodonga region.

Firstly, a stepped sequence of residual ridges and hills on the higher valley sides formed, mainly by landscape degradation during the development of the Yackandandah (AW11) and Gundowring (AW10) pedo-morpholiths. Secondly, there are the breaks in slope on the gentle footslopes of the valley sides which resulted from valley-in-valley developments mainly related to the Gundowring (AW10), Baranduda (AW9), and Mudgeegonga (AW8) pedo-morpholiths. Thirdly, there are the terraced remnants of colluvial and alluvial mantles in the central valley to which all four pedo-morpholith developments of this period contributed.

(iii) During the third main geomorphogenetic period, embracing the eight pedo-morpholiths of group I (Table 1) only relatively minor landscape modifications occurred. The more significant were virtually restricted to terracing in low alluvial and colluvial belts of the valley floors, and to some stripping and ravine development on very steep slopes. Terraces of the four older pedo-morpholiths of this period (sub-group Ib, Table 1) generally dominate in the smaller tributary valleys, whereas the terraces of the younger set (sub-group Ia, Table 1) dominate on the floodplains of the main streams. The terrace of the Barnawartha (AW5) unit is often prominent in both situations.

The cross-section of Fig. 8 illustrates the results of the soil-geomorphic developments of the three main periods summarized above on the soil landscape development of the major valleys. The deep central valley fill is characteristic but deposition on the wide gently sloping margins is generally confined to relatively thin sheets of pedisediments overlaying more or less decomposed rock and to local fans of the valley side tributaries. This is in contrast to the type of valley cross-section described by Lawrence *et al.* (1976, Fig. 9 2B) for major valleys in the adjacent mountainous regions where deep depositional bodies are shown across most of the valley section with a base and central core of alluvium and deep piedmont deposits on the upper sides.

The strong topographic contrasts which have developed during the development of the pedo-morpholiths indicate a considerable age span during the evolution of the present soil mantle. No actual dates for pedo-morpholith development are available but a tentative correlation with soil stratigraphic layers in the Goulburn Valley dated by Bowler 1967 can be made. These were assessed as between 250 and 30,000 years, and can be arranged in a sequence of increasing age on the basis of the pedological characteristics of sola and subsola which appear to correspond to the sequence of soils found on the five youngest pedo-morpholiths in the Albury-Wodonga region. According to this tenta-

tive correlation, the oldest dated soil sediment (about 30,000 years) in the Goulburn Valley seems to correlate with the Boorgunyah (see I-b in Table1).

A tentative appraisal of the age of the older pedo-morpholiths of the high valley sides can be attempted through their geomorphic resemblance to the piedmont landscapes flanking the Central Highlands (Jenkin 1976, Table 10.1, p. 331). Jenkin implies that these piedmont landscapes probably orginated in late Tertiary times. A considerable age for the older pedo-morpholiths is also indicated by the similarity of their pedological patterns to those of lateritic soils on land surfaces of Tertiary age.

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